

Marine cyanobacterial, algal and plant biodiversity in southeast Queensland: knowledge base, issues and future research directions

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ABSTRACT

Cyanobacteria, algae, seagrasses and mangroves contribute significantly to marine ecosystem function in their roles as primary producers underpinning marine food webs, as 'ecosystem engineers' providing habitat, and in modulating global biogeochemical cycles and stabilising shorelines. Species-level knowledge for these organisms in southeast Queensland varies greatly, with the relatively few seagrass and mangrove species well studied compared to the underdescribed and undersampled algae and cyanobacteria. Algal/cyanobacterial species richness for the region is high but data on biodiversity patterns of these organisms and the ecological processes that cause, maintain and regulate these patterns are dismally incomplete. There are no comprehensive algal/cyanobacterial floras for eastern Australia, ensuring that numerous species are difficult to identify with certainty and thus can not be effectively treated in scientific studies. Accurate identification and knowledge of algal/cyanobacterial biology and ecology at the species level are essential prerequisites underpinning biotic surveys, biomonitoring programs and management strategies for algal/cyanobacterial blooms, exotic species, climate change, rare and threatened species and marine protected areas. Research programs documenting species composition and abundance in marine communities and the ecological and geographical distribution of species are urgently required to provide rigorously-collected data on the ecologically-important cyanobacteria and algae in southeast Qld in order to provide the scientific basis underpinning marine environmental management and marine conservation initiatives, particularly biodiversity conservation. The inability to identify species seriously imperils efforts directed towards arresting the irreversible loss of biodiversity. □ *cyanobacteria, algae, seagrasses, mangroves, biodiversity, conservation, Australia.*

Although widely acknowledged to exist at multiple levels of biological organisation ranging from genes to ecosystems, it is understanding biodiversity at the species level that plays a central role in our efforts to conserve species and the habitats, ecosystems and biomes in which species live (May 1995; National Research Council 1995; Bianchi & Morri 2000; Mikkelsen & Cracraft 2001; Mace 2004). Biodiversity results from the diversification of species. Species

composition generally plays a crucial role in ecosystem dynamics and function (Dayton 1972; Knowlton & Jackson 1994; Jones *et al.* 1997; Tilman 1999; Loreau *et al.* 2001; Altieri *et al.* 2007). Species drive ecological processes which will undergo functional shifts when sets of species are lost or replaced by other species with differing traits and interactions. Biological impoverishment through species loss reduces the resilience of ecosystems to environmental

change, an important concept underpinning the endeavours of conservation biology which aims to protect not only 'iconic species' but also a wide range of species, including many poorly known and often overlooked species (Murphy & Duffus 1996; Mikkelsen & Cracraft 2001; Clarke & May 2002, Roberts *et al.* 2003; Kenworthy *et al.* 2006), many of which contribute greatly to the sustainability of life on Earth (Corliss 2002).

Surprisingly, the great majority of species on Earth are unknown to science (Raven & Wilson 1992; May 1995; Wilson 2000, 2002; Mace 2004; Crisci 2006; Hodkinson & Parnell 2006). Between 1.5 and 1.8 million species have been described, with conservative estimates of 7 to 15 million species yet to be discovered. Thousands of species, both known and unknown, are threatened by an accelerating rate of extinction, correlated to an increasing human population. Loss of two-thirds of all species on Earth is predicted by the end of this century (Raven 2002 and references therein). Unfortunately, our ability to devise science-based action plans to save species from extinction is severely limited by the fragmented knowledge base in which < 1% of described species are estimated to have been studied beyond the meagre essentials of morphology, habitat preference and geographical location (Wilson 2000; Crisci 2006). Biodiversity loss is irreversible, and unfortunately our ignorance of the biota ensures that we are ill-equipped to both understand the significance of its loss, and protect against it (Clarke & May 2002; Dayton 2003).

The pressing need for marine conservation was first recognised by Kaufman (1988) who challenged the then widely accepted scientific and popular belief that marine ecosystems were beyond the deleterious impacts of the human race. We now know that marine ecosystems have been dramatically degraded (Ray & Grassle 1991; Norse 1995; Dayton 2003) and continue to be threatened by the over-exploitation of natural resources, increasing habitat alteration and degradation, worsening eutrophication, introduction of alien species and the impacts of global climate change (Norse 1993; National Research Council 1995). Unfortunately, marine ecosystems and marine biodiversity have been far less studied than their

terrestrial equivalents (Kaufman 1988; Murphy & Duffus 1996; Bianchi & Morri 2000; Kochin & Levin 2003; Boudouresque *et al.* 2005), resulting in fragmentary historical data sets on species composition and abundances in marine communities. Also of great concern is the marked lack of recent reliable data on changes in species composition and abundances in many marine systems (Boudouresque *et al.* 1995; Bianchi & Morri 2000; Hiscock *et al.* 2003).

Little is known of the scale and rate of species loss resulting from anthropogenic impacts on marine ecosystems (Kaufman 1988; Carlton *et al.* 1991, Carlton 1993; Norse 1993, 1995; Roberts & Hawkins 1999). Known marine extinctions were limited to relatively few megavertebrate species (Norse 1993; Vermeij 1993), reflecting the difficulty in detecting extinctions of inconspicuous marine species. Furthermore, the full extent of this irreversible biodiversity loss may never be realised because many marine species may have been exterminated before discovery (Roberts & Hawkins 1999; Dayton 2003). The first documented marine invertebrate neoextinction (the eelgrass limpet) was reported 50 years after the event (Carlton *et al.* 1991). Subsequently, several more marine invertebrate neoextinctions have been reported (Carlton 1993; Roberts & Hawkins 1999). Similarly, data on algal extinctions is also sparse, with *Vanvoorstia bennettiana* Harvey last recorded for Port Jackson nearly 150 years ago the only alga regarded as extinct (Millar 2003).

The extent of biodiversity encompassed by cyanobacteria, algae, mangroves and seagrasses is enormous, representing five of the six Kingdoms of Life (Keeling 2004; Palmer *et al.* 2004) (Table 1). Although these phototrophic organisms are commonly referred to as 'marine plants', only the Chlorophyta (green algae) which are the ancestors of the land plants, Rhodophyta (red algae), mangroves and seagrasses belong to the Plant Kingdom. Other algal phyla are assigned to three other Kingdoms with the prokaryotic Cyanobacteria in the fifth Kingdom. These differing evolutionary histories have profound effects on the biology, physiology and ecology of organisms which must be understood before effective management and conservation initiatives can be devised. Cyanobacteria and algae evolved in and developed

Table 1. Species richness of marine phototrophs. Based on Brodie & Zuccarello 2006¹; Williams & Reid 2006²; Saenger 2002³; Den Hartog & Kuo 2006⁴; Phillips 1998a⁵.

Kingdom	Taxa	Estimated described (total species) worldwide	Known species richness in SE Qld
Bacteria	Cyanobacteria	2 000 (?) ^{1,2}	?
Excavates	Euglenophyta	959 ^{1,2}	?
Alveolates	Dinophyta (dinoflagellates)	1240 (11 000) ^{1,2}	?
Chromista	Phaeophyta (brown algae)	1718 (2000) ^{1,2}	51 ⁵
	Chrysophyta (golden algae)	2 400 (5 000) ^{1,2}	?
	Bacillariophyta (diatoms)	6423 (200 000) ^{1,2}	?
	Haptophyta (coccolithophorids)	510 (2000) ^{1,2}	?
	Cryptophyta (cryptomonads)	85 (1200) ^{1,2}	?
Primoplantae	Chlorophyta (green algae)	3215 (20 000) ^{1,2}	65 ⁵
	Rhodophyta (red algae)	5781 (20 000) ^{1,2}	161 ⁵
	Mangroves	84 ³	8
	Seagrasses	64 ⁴	8

the adaptations necessary for life in aquatic environments. By contrast, mangroves and seagrasses which colonised the marine environment during the late Cretaceous/ early Tertiary have retained most features characteristic of their land plant ancestors (Saenger 2002; Kuo & Den Hartog 2006). Seagrasses are unique, being the only submarine flowering plants on Earth. Relatively few species of flowering plants (only seagrasses and mangroves) have adapted to life in the harsh environment of the land/sea interface (Table 1).

Approximately 350,000 algal species are estimated to occur on Earth, similar to the species richness for higher plants (World Conservation Monitoring Centre 1992; Williams & Reid 2006; Brodie & Zuccarello 2006). Algal species are generally poorly known, with fewer described species compared to higher plant species. Species richness and the proportion of described to undescribed species varies among the algal phyla (Table 1). The diatoms, whose first representatives appeared in the fossil record circa 190 million years ago (Sims *et al.* 2006), are both the most speciose and poorly known phylum, with only approximately 4% of species described. The sister group of the diatoms, the Bolidiophyceae, comprises 3–5 species of small flagellates discovered during the last decade (Guillou *et al.* 1999). Among the seaweeds, the

red algae, an ancient lineage dating back to the oldest (1200 million years old) resolvable eukaryotic fossil *Bangiomorpha pubescens* Butterfield (2000) are the most speciose macroalgal phylum, with approximately 25% of species described by science.

This paper establishes the crucial role that marine phototrophs play in marine ecosystems and reviews the species-level knowledge base for these organisms in southeast Queensland, a region defined geographically from Noosa to Coolangatta in the tropical to temperate biogeographic overlap zone on the Australian east coast. For this region, species of marine cyanobacteria and algae are poorly known whereas seagrass and mangrove species are comparatively well known. The importance of detailed taxonomic, ecological and biogeographic data on the marine phototrophic species is discussed in relation to biotic surveys, biomonitoring, algal blooms, invasive exotic species, rare and threatened species and marine protected areas. Future research directions are outlined to collect much needed data on species composition, abundance, ecological and geographical distribution patterns of cyanobacterial and algal species in marine communities of SE Qld at varying spatial and temporal scales, highlighting the pressing need for rigorously-collected detailed data at the species level to underpin marine management and conservation planning.

SIGNIFICANCE OF MARINE PHOTOTROPHS

Phototrophs are of great ecological, conservation and economic importance in marine ecosystems, providing a wide range of essential 'ecosystem services' (Myers 1996; Costanza *et al.* 1997) that sustain ecosystem function, the human race, and the health of our planet. Considering only two ecosystem services, estuarine algal/seagrass beds are valued at \$US19,004 ha⁻¹ year⁻¹ for the recycling of nutrients and raw materials (Costanza *et al.* 1997) and \$US30,000 ha⁻¹ year⁻¹ in fishery production (Virmstein & Morris 2000). Loss of vital ecosystem services from estuaries degraded by coastal development and pollution costs the US more than \$200 million year⁻¹ in lost commercial fish production (Myers 1996). Marine phototrophs contribute significantly to numerous ecosystem services including primary production, habitat heterogeneity, biogeochemical cycling, biostabilisation of sediments, and are also useful as environmental indicators and sources of marine natural products.

1. PRIMARY PRODUCTION AND ENERGY FLOW IN MARINE FOOD WEBS

As primary producers, cyanobacteria, algae, seagrasses and mangroves underpin marine food webs in a biosphere where total global marine and terrestrial net primary production are similar (Field *et al.* 1998). Algae are the major marine primary producers in all marine ecosystems (Mann, 1973, 1988; Field *et al.* 1998). Phytoplankton support oceanic and coastal food webs (Mallin & Paerl 1994; Deegan & Garritt 1997; Falkowski *et al.* 1998; Calbet & Landry 2004). Algal turfs and symbiotic dinoflagellates in corals contribute about 50% and 30% of the primary production of healthy coral reef ecosystems respectively (Adey & Steneck 1985; Klumpp & McKinnon 1989; Adey 1998), with 60–100% of turf algal production consumed by the intense grazing pressure of herbivores (Adey & Steneck 1985; Adey & Goertemiller 1987; Klumpp & McKinnon 1989). Cyanobacterial and/or algal mats/biofilms adhering to muddy/sandy substrata are often the dominant primary producers in estuarine ecosystems (Underwood & Kromkamp 1999). Algal primary production (benthic microalgae, epiphytes, phytoplankton) in seagrasses communities often far exceeds

seagrass primary production (Kitting *et al.* 1984; Daehnick *et al.* 1992; Mateo *et al.* 2006), with a large proportion (20–62%) of epiphyte primary production consumed by herbivores (Klumpp *et al.* 1992). Mangrove and seagrass communities are highly productive, but most production enters detrital food webs (Newel *et al.* 1995, Marguillier *et al.* 1997; Valentine & Duffy 2006), with low proportions (10–30%) of seagrass production removed by herbivores (Mateo *et al.* 2006; Valentine & Duffy 2006).

2. HABITAT HETEROGENEITY

Mangrove, seagrass, macroalgal and cyanobacterial species are 'foundation species' (Dayton 1972, 1975) or 'ecosystem engineers' (Jones *et al.* 1994), structuring the local environment to either positively or negatively affect the survival of other species in the community. Foundation species increase habitat heterogeneity and supply predator protection for many organisms, including juvenile stages of commercially-exploited fishery species (Brawley & Adey 1981; Kitting *et al.* 1984; Poore 1994; Haywood *et al.* 1995; Heck *et al.* 2003; Gillanders 2006). Seagrass, mangrove and kelp communities are widely acknowledged as foundation species but many other algal/cyanobacterial species also fulfil this important ecological role. For example, the green alga *Halimeda* and coralline red algae are 'ecosystem engineers' on coral reefs, with CO₃ sediments derived from these calcareous algae being quantitatively more important for coral reef construction than CO₃ sediments from corals (Stoddart 1969; Milliman 1974, Hillis-Colinvaux 1980; Drew 1983; Rees *et al.* 2007). Encrusting coralline red algae provide further ecosystem services by retarding reef erosion from high-energy oceanic waves by overgrowing, cementing and stabilising calcareous sediments on outer reef rims (Womersley & Bailey 1969; Littler & Doty 1975; Littler & Littler 1984; Adey 1998).

3. GLOBAL BIOGEOCHEMICAL CYCLES

Marine phototrophs are important in the global carbon cycle, removing CO₂ from atmospheric and oceanic sinks and sequestering some of C fixed by phytoplankton by sedimentation in the ocean depths (Raven & Falkowski 1999) and in CO₃ sediments in *Halimeda* biotherms on coral reefs (Rees *et al.* 2007). Phytoplankton,

particularly species forming massive oceanic blooms, and macroalgae play a central role in the global sulphur cycle, being the major source of atmospheric dimethyl sulphide, a compound which forms cloud condensation nuclei and cloud droplets to bioregulate climate by influencing the Earth's radiation budget (Charlson *et al.* 1987; Bates *et al.* 1992; Malin & Kirst 1997). Nitrogen-fixing cyanobacterial species are important in the global nitrogen cycle, potentially adding tons of N to marine ecosystems during blooms (Capone *et al.* 1997).

Algal and cyanobacterial mats are important in the regulation of the benthic-pelagic nutrient cycling loops (Lapointe & O'Connell 1989, Lavery & McComb 1991, Thybo-Christesen *et al.* 1993, Valiela *et al.* 1997, Sundback *et al.* 2003).

4. BIOSTABILISATION OF SEDIMENTS

Mangroves, seagrasses, algal and cyanobacterial mats stabilise unconsolidated sediments by reducing the erosive capability of seawater passing through/over these communities (Yallop *et al.* 1994; Underwood 1997; Paterson & Black 1999; Gacia & Duarte 2001; Saenger 2002; Kenworthy *et al.* 2006). Decreasing water velocity increases sedimentation of particulate matter, improving water clarity and reducing water column nutrient levels. Mangrove canopies also reduce wind velocities, thus protecting terrestrial vegetation and buildings during storms and cyclones.

5. INDICATORS OF ENVIRONMENTAL HEALTH

Decreases in seagrass depth ranges or in the areal extent of seagrass communities are used to monitor seagrass ecosystem health (Dennison & Abal 1999). Algal species respond quickly to environmental change with changes in species composition and abundance. Eutrophication usually results in decreased algal species richness, changes in species composition and community complexity (Littler & Murray 1975; Lapointe & O'Connell 1989; Brown *et al.* 1990; Hardy *et al.* 1993, Middelboe & Sand-Jensen 2000). Algal species intolerant to fluctuating salinities, elevated nutrient levels and toxic substances are replaced by fewer tolerant species which dramatically increase in abundance. Sensitivity of early developmental stages of algal species to low concentrations of toxicants is used by bioassays to assess water quality (Reed *et al.* 1994; Kevekordes 2001).

6. NATURAL PRODUCTS

Marine algae are used extensively for human and animal food and in industrial and medical products (Borowitzka & Borowitzka 1988; Lembi & Waaland 1988). In 2004, mariculture of *Laminaria japonica* (kombu), *Porphyra* (nori), and *Undaria pinnatifida* (wakame) produced 4.5, 1.4 and 2.5 million metric tons valued at 2.75, 1.34 and 1.02 billion US\$ respectively (FAO 2006), being used primarily for human food. The red alga *Porphyra* is used as the outer wrapper in sushi. Hydrocolloids extracted from excess maricultured and wild-collected kelps (alginates) and red algae (agar, carrageenans) are used in the food processing industries. Antifouling agents added to marine paints have been extracted from algae (de Nuys & Steinberg 1999). Marine algae exhibiting antibacterial, agglutinin, anti-fungal, anticoagulant, antitumor and antiviral activity are potential sources of new bioactive chemicals, important for supplying new drugs to combat resistant infectious and newly emergent diseases.

KNOWLEDGE BASE

The biodiversity of mangrove and seagrass species of SE Queensland is well known. Eight mangrove species occur in sheltered bays and estuaries in the region (Hegerl & Timmins 1973; Shine *et al.* 1973; Dowling 1979, 1986; Davie 1984, 1992; Hyland & Bulter 1988), all of which are widely distributed in the tropical Indo-West Pacific. In SE Qld, *Avicennia marina* (Forssk.) Vierh. is the most ecologically widespread and abundant species with *Rhizophora stylosa* Griff. and *Aegiceras corniculatum* (L.) Blanco also common. *Lumnitzera racemosa* Willd. and *Excoecaria agallocha* L. reach their southern distribution limit in Moreton Bay (Macnae 1966). The mangrove fern *Acrostichum speciosum* Willd. is found in tidal creeks and swamps in the region. Hyland & Bulter (1988) surveyed the species composition and distribution of mangrove communities in SE Qld, which are best developed on the muddy deltas of the Logan, Pimpama and Coomera Rivers in southern Moreton Bay. These communities are unique being the largest area of mangroves on the east Australian coast south of the Wet Tropics region.

Eight species of seagrasses (including *Halophila minor* (Zoll.) Hartog, this volume) inhabit the

sheltered estuaries and bays of SE Qld (Young & Kirkman 1975; Kirkman 1975; Poiner 1985; Hyland *et al.* 1989; Poiner *et al.* 1992; Dennison & Abal 1999; McLennan & Sumpton 2005). With the exception of *Zostera capricorni* Asch. which is geographically limited to eastern Australia, New Guinea and New Zealand, the other species are widely distributed in the tropical Indo-West Pacific. Moreton Bay is the southern distribution limit of *Syringodium isoetifolium* (Asch.) Dandy, *Cymodocea serrulata* (R.Br.) Asch. ex Magnus and *Halodule uninervis* (Forssk.) Asch. (Poiner & Peterkin 1995). *Zostera capricorni* is the most abundant and widespread species in the region, frequently growing as mono-specific meadows. The clear oceanic-influenced waters of eastern Moreton Bay support the most species-rich and abundant seagrass communities in the region, unlike western Moreton Bay where high turbidity limits seagrass growth (Young & Kirkman, 1975; Poiner, 1985; Abal & Dennison, 1996).

Our knowledge of the marine algal and cyanobacterial species of SE Qld is dismally incomplete, these species having received minimal taxonomic and ecological study. There are no comprehensive marine algal/cyanobacterial floras for the Australian east coast, and this represents a major impediment to including these organisms in ecological surveys, documenting biodiversity patterns or devising strategies for marine environmental management and conservation planning. Algal and cyanobacterial species are common on rocky shores, deep rocky reefs, sand and mud flats, and in seagrass and mangrove communities in SE Qld, but with the lack of adequate sampling or study, the identity of many local species may not be accurately known, and species richness and endemism may be underestimated.

Knowledge of the marine macroalgal (Chlorophyta, Phaeophyta, Rhodophyta) species of SE Qld is largely limited to eight scientific papers (Askenasy 1894; Johnston 1917; Cribb 1979; Saenger 1991; Phillips 1997b, 1998a, Phillips, 2002; Phillips & Price 1997) and references to various species scattered throughout the scientific literature. Based on vouchered herbarium specimens at the Queensland Herbarium (BRI), approx. 275 species have been collected from

Caloundra to Jumpinpin over the last 100 years (Phillips 1998a). While the BRI macroalgal collection is extremely valuable and indicates high macroalgal species richness for this poorly studied region, limitations of these data ensure that they are inadequate for the purposes of environmental management and conservation planning for the following reasons:

1. Specimens have been updated to currently accepted names, but with the exception of some brown algal species (Phillips & Price 1997), many species identifications have generally not been verified (though they could be with further taxonomic study). Thus the collection undoubtedly includes misidentified species, species whose concepts have changed following subsequent taxonomic revision, and species new to science. It is vital that herbarium specimens bear the correct species name as this establishes a species' biological identity and its ecological role. As Gotelli (2004) emphasises, correct identifications are crucial for reliable community analyses.

2. Specimens result from opportunistic and sporadic collecting over the last 100 years and not from surveys using standardised sampling effort. The number of species recorded at a locality is related to sampling effort (Womersley & Bailey 1970; Edgar *et al.* 1997; Middelboe *et al.* 1997; Bianchi & Morri 2000; Gotelli 2004). Therefore, comparisons of macroalgal species richness at different localities, or documenting macroalgal distribution patterns based on a highly variable sampling effort, are scientifically flawed. The most species rich localities, Caloundra (103 species) and Redcliffe (109 species), were sampled on many occasions and cannot be compared with sites sampled only once to record <10 species.

3. Specimens were not collected as part of a quantitative sampling program using standard ecological techniques and consequently there is no data on species abundance, community structure or on the spatial and temporal variability in macroalgal communities on annual, decadal or longer time scales. There is also little indication whether small, inconspicuous, subtidal, or seasonal macroalgal species were included in the collections. Furthermore, locality data from the many drift specimens is unreliable,

apparent from the Noosa collection of the temperate brown alga *Hormosira banksii* (Turner) Decne., which has a northern geographical distribution limit in northern NSW.

Current knowledge indicates that macroalgal species with tropical affinities predominate in Moreton Bay (65%), with cool temperate species ranging from southern Australia (15.2%) and species with cosmopolitan distribution patterns (20.8%) also contributing to the flora (Phillips 1998a). In SE Qld, macroalgal communities are best developed on rocky substrata on the Redcliffe Peninsula, on rocky headlands of the wave swept coasts (pers. observ.) and on deep water rocky outcrops east of Stradbroke and Moreton Islands (Stevens & Connolly 2005). In sheltered areas with muddy/sandy substrata, macroalgal species grow on firm substrata such as mollusc shells, rocks and pebbles and as epiphytes on mangrove roots and seagrasses.

Little is known of the biodiversity of marine phytoplankton of SE Qld despite these organisms fixing approx 60% of the total primary production of the Moreton Bay ecosystem (Eyre & McKee 2002). Currently, there is no phytoplankton species list and little data on the ecology of phytoplankton communities in SE Qld, but species richness is expected to far exceed that of the macroalgae. Phytoplankton communities are generally spatially variable, evident from domination by either tropical Coral Sea dinoflagellates particularly *Ceratium* spp. or the diatom *Paralia sulcata* (Ehrenberg) Cleve (as *Melosira sulcata* (Ehrenberg) Cleve) and the dinoflagellate *Dinophysis caudata* Saville-Kent in the oceanic and estuarine sections of Moreton Bay respectively (Ferguson-Wood 1964). Phytoplankton communities are generally composed of many different algal phyla. This is typified by a winter flood-influenced community in western Moreton Bay that comprised 145 species, including diatoms (81 species), dinoflagellates (54 species) and 1–2 species each of cryptophytes, chrysophytes, euglenophytes, prasinophytes and rhabdophytes (Heil *et al.* 1998a, b). The flood would be expected to shift phytoplankton species composition to more euryhaline species and consequently the lack of baseline monitoring data on species composition and abundance precludes interpretations of the

flood data collected during both a narrow sampling window and atypical prevailing environmental conditions. Phytoplankton blooms regularly occur in Moreton Bay but have not been documented in the scientific literature. The surf-zone diatom *Ananlus australis* Drebes *et* Schultz is recorded as blooming at Main Beach, Southport (Hewson *et al.* 2001) and more generally along SE Qld coasts (pers. observ.).

With the exception of *Lyngbya majuscula* (Dillwyn) Harv. and *Trichodesmium*, little is known of the marine cyanobacterial species of SE Qld. Cribb (1979) recorded 13 cyanobacterial species from salt marshes and mangroves in Moreton Bay, but this number gives little indication of cyanobacterial species richness for the region. Abundant thick mats of *Microcoleus chthonoplastes* Thur. ex Gomont, a species not previously recorded from Moreton Bay, are reported from areas of mangrove dieback at Whyte Island (Phillips & Kevekordes 2008).

Species richness or community structure of the microphytobenthos of Moreton Bay which is estimated to fix 85,000 t C year⁻¹ (Eyre & McKee 2001) has not been documented. Microphytobenthos typically occurs as either microbial mats or biofilms on sandy/muddy substrata (Yallop *et al.* 1994). Stratified microbial mats are often mm thick, and are composed of three layers: an upper-most diatom mucopolysaccharide layer, a species-rich diatom midlayer, and a lower-most layer of filamentous cyanobacteria, often *Microcoleus chthonoplastes*, although species of *Oscillatoria*, *Spirulina*, *Merismopedia*, *Gloeotheca*, *Lyngbya* and *Phormidium* may also be present. Biofilms are composed of many diatom species and diatom mucopolysaccharide and tend to be transient, relatively thin (100 µm) and unstratified. Microphytobenthic communities typically comprises 50 to 100 species at a locality (Underwood 1997, 2002; Underwood *et al.* 1998).

ISSUES

NEED FOR TAXONOMY

Taxonomic studies are urgently required to fully document biodiversity of marine cyanobacteria and algae of SE Qld by defining undescribed, under-described and inaccurately described species and compiling this data into

floras/field guides for the region. Taxonomy is the science that not only discovers and documents biodiversity (Wilson 2000, 2002) but also provides the biological reference system for recognising and naming species. The southern Australian marine macroalgal flora has been well documented, most recently in the six volumes of the 'Marine Benthic Flora of Southern Australia' (Womersley 1984, 1987, 1994, 1996, 1998, 2003) which has enabled these species to be included in many ecological and conservation studies, including analyses of the patterns of species richness and endemism (Phillips 2001). It is difficult to study or conserve species that can not be identified with certainty (Dayton 2003; Mace 2004). Species are unique entities, conveyed by the species name which is not an arbitrary concept, but a summary of the morphological, ultrastructural, physiological, biochemical, ecological, geographical and phylogenetic characteristics of the entity.

Our inability to recognise species has important implications for environmental and conservation management, clearly demonstrating that these strategies are as effective as the reliability of the taxonomy on which they are based (Knowlton *et al.* 1992; Knowlton & Jackson 1994; National Research Council 1995; Wilson 2000; Knowlton 2001; Womersley 2006). Environmental and conservation management must be underpinned by taxonomic precision and accuracy. Identifying constituent species is the key to understanding community structure and function, and for detecting the early warning signals of environmental change before large scale environmental degradation and massive species loss become apparent (National Research Council 1995; Dayton 2003). How can we effectively manage or conserve the many species we cannot recognise? This is particularly pertinent for many widely distributed cosmopolitan or pantropical marine 'species' now known to be 'species complexes' comprising two or more, often endemic, superficially similar sibling or cryptic species (National Research Council 1995). Prevalence of cryptic marine species has ensured that not only has marine biodiversity been underestimated (eg actual invertebrate species richness is three to five times higher than previously recognised for well studied coral reef

communities (see Knowlton & Jackson 1994 for review)) but also marine species generally have been erroneously thought to be common and widely distributed, two features thought to protect species from extinction (Roberts & Hawkins 1999). Many cryptic marine macroalgal species with restricted geographical ranges have been identified, necessitating the description of new genera (Phillips 1997a; Nelson *et al.* 2006) and new species (Phillips & Nelson 1998; Zuccarello & West 2003, 2006; Nelson *et al.* 2006; Zuccarello *et al.* 2006; Verbruggen *et al.* 2006). New conservation strategies will have to be developed for the marine biota that has more geographically restricted species than previously thought.

QUANTITATIVE BIOTIC SURVEYS

Biotic surveys are urgently required to address the complete lack quantitative data on the marine algae/cyanobacterial communities of SE Qld. These data are important for environmental management and conservation planning. It is expected that these assemblages will be spatially variable, occurring in different habitats such as the red algal *Bostrychia/Caloglossa* association characteristic of mangroves and also that seemingly similar habitats will have differing algal/cyanobacterial assemblages. These assemblages will also exhibit considerable temporal variability on seasonal, annual, decadal and longer term time scales in response to environmental variables. Ecological processes affecting algal/cyanobacterial community structure are complex and long term baseline datasets are required to separate natural variability from anthropogenic impacts, and to determine the effects of slow processes (eg global warming), episodic phenomena and high annual variability (Hawkins & Hartnoll 1983; Dayton & Tegner 1984; Southward 1991, 1995; Barry *et al.* 1995; Lewis 1996; Hiscock *et al.* 2003; Thibaut *et al.* 2005).

BIOMONITORING

Biomonitoring provides accurate appraisals of ecosystem health by sampling the biota which reflect the summation of all environmental variables over spatial and temporal scales rather than those variables present during sampling or being studied (Baldwin & Kramer 1994; Abel 1996). Currently, physico-chemical parameters

are monitored in SE Qld estuaries but these, even when monitored at frequent intervals, often fail to detect the delivery of episodic pulses of biologically-significant often peak concentrations of pollutants and nutrients into ecosystems. This is well illustrated by seasonal macroalgal blooms which inhabit apparently oligotrophic (nutrient-poor) waters (Lapointe & O'Connell 1989; Thybo-Christesen *et al.* 1993; Peckol *et al.* 1994), the result of bloom-forming algae absorbing high levels of spatially and temporally variable pulses of water column nutrients within hours or days (Kiirikki & Blomester 1996; Fong *et al.* 1993a, b; Kamer *et al.* 2001).

Seagrass depth ranges are currently used for monitoring water quality in Moreton Bay (Dennison & Abal 1999), a technique based on declines in many Australian seagrass communities attributed to decreased submarine light penetration from increased water turbidity or epiphyte growth (Bulthuis 1983; Cambridge & Mc Comb 1984; Cambridge *et al.* 1986; Abal & Dennison 1996). However, seagrasses occupy <5% of the area of Moreton Bay leaving an urgent need for a more widely applicable bio-monitoring system for the bay.

Algal and cyanobacterial species are valuable indicators of ecosystem health (both pristine and degraded ecosystems), responding quickly to anthropogenic-induced changes to the marine/estuarine environments with changes in species composition and abundances in these communities. Marked shifts in dominance from slow-growing perennial macroalgal species of healthy ecosystems initially to smaller frondose algae and then finally to fast-growing filamentous 'nuisance' macroalgal species are early warning signals of increasing nutrient enrichment, triggers to reduce high nutrient loading into aquatic systems long before eutrophication results in catastrophic algal blooms (Littler & Murray 1975; Valiela *et al.* 1997; Örnólfsson *et al.* 2004).

ALGAL BLOOMS

The ongoing and worsening problem of coastal eutrophication has resulted in the increased frequency and intensity of algal blooms worldwide (Hallegraeff 1993; Chrétiennot-Dinet 2001). Management strategies to ameliorate decadal long macroalgal blooms aim to reduce high N

and P loadings into eutrophic estuaries by 30–80% (Jorgensen & Richardson 1996; Boesch *et al.* 2001; Paerl *et al.* 2003). Knowledge of the biology and ecology of bloom-forming species is also necessary in order to understand why these species cause shifts in species composition in communities and maintain prolonged competitive dominance (Valiela *et al.* 1997; Smayda 1997; Millie *et al.* 1999).

Transient algal and cyanobacterial blooms which regularly occur in SE Qld coastal waters can be expected to become more common with the increasing human population in the region. Species of the 'green tide' genera *Cladophora*, and *Ulva* (which now includes *Enteromorpha*) and phytoplankton (such as *Heterosigma akashiwo* (Hada) ex Sournia, *Prorocentrum micans* Ehrenberg, *Scrippsiella trochoidea* (Stein) Balech ex Loeblich III) commonly form blooms in the region, but it is the cyanobacterial species *Lyngbya majuscula* and *Trichodesmium* and the brown alga *Hinckesia sordida* (Harvey) Silva which have had the greatest impact in SE Qld. Periodic, short lived (eg days) blooms of the tropical planktonic *Trichodesmium* (often commonly and erroneously referred to as 'coral spawn') are transported into coastal waters in SE Qld and many localities to Tasmania by the southward flowing East Australian Current (Ajani *et al.* 2001).

Recurrent nuisance blooms of *Lyngbya majuscula* have been apparently restricted in Moreton Bay to the eastern banks, Deception Bay and Pumicestone Passage. The supply of either or both N and P control peak rates of primary production of bloom-forming species in estuaries (Valiela *et al.* 1997). However, *Lyngbya majuscula* bypasses N limitation by fixing N₂ in the dark (Lundgren *et al.* 2003; Elmetri & Bell 2004), and not in the light (Dennison *et al.* 1999) when oxygen-labile nitrogenase is degraded during photosynthesis.

The macronutrients N and P have the greatest potential to constrain algal/cyanobacterial growth (Cloern 2001; Twomey & Thompson 2001; Miao *et al.* 2006). If the micronutrient Fe limits the growth of *Lyngbya majuscula* in Moreton Bay (Dennison *et al.* 1999), P would have to be in excess, contrary to studies which report both the Bay (Eyre & McKee 2002) and

growth of Moreton Bay *Lyngbya majuscula* (Elmetri & Bell 2004) to be PO₄ limited. Clearly, Fe limits cyanobacterial/algal growth in high nutrient/low chlorophyll remote oceanic regions (Coale *et al.* 1996; Behrenfeld & Kolber 1999), where Fe can not be recycled from the ocean depths and is quickly depleted from surface waters unless replenished by the atmospheric transport of terrestrial aeolian dust (Duce & Tindale 1991; Zhaung *et al.* 1999). In contrast to these oceanic regions, Moreton Bay has high chlorophyll levels, the sediments are Fe-rich (Preda & Cox 2002) and there should be sufficient bioavailable Fe²⁺ from organic material supplied by riverine inputs (Johnson *et al.* 1999; Wetz *et al.* 2006, Tovar-Sanchez *et al.* 2006). Furthermore, ambient seawater NO₃ levels >2.5 µM common in Moreton Bay would inhibit the energetically-expensive N fixation in *Lyngbya majuscula*, similar to the inhibition demonstrated in *Trichodesmium* (Mulholland *et al.* 2001; Holl & Montoya 2005), thus reducing the Fe requirement for nitrogenase and associated metabolic pathways (Howarth *et al.* 1988; Paerl 1990). This would also be a plausible explanation for the low rates of N₂ fixation reported for Moreton Bay *Lyngbya majuscula* by Watkinson *et al.* (2005).

During the spring/early summer of 2002 to 2005, *Hincksia sordida* bloomed in the Noosa River estuary and at Main Beach, Noosa, greatly affecting the recreational use of the popular swimming beach (Phillips 2006). During blooms, bulldozers removed the decomposing algal masses fouling the beach, but large amounts remained suspended in the surf. *Hincksia sordida* is an estuarine alga, reported to grow to one metre in length in sheltered Moreton and Port Phillip Bays. The source of the massive injections of nutrients into the Noosa River system and Laguna Bay need to be identified and reduced in order to prevent future blooms in the area.

EXPECTED EFFECTS OF CLIMATE CHANGE

Average global surface temperature has increased during the generalised warming trend of the last 150 years. Sea surface temperature (SST) which is projected to rise by 2–3 °C around the Australian continent by 2070 may potentially affect the physiology, phenology

and geographical distribution of marine species (Hughes 2000). Relatively small changes in temperature have already affected marine species (Barry *et al.* 1995; Southward *et al.* 1995; Sagarin *et al.* 1999), including dramatic declines in the kelp forests on the Tasmanian east coast (Edyvane 2003), but there is little understanding of the effects on the marine biota of larger increases in SSTs. We do know that during the Quaternary warming episodes, terrestrial plant species responded independently and not as a community moving at different rates and in different directions during climate-induced latitudinal shifts in geographical range (Davis & Bodkin 1985; Overpeck *et al.* 1991; Jackson & Overpeck 2000; Hannah *et al.* 2005). Consequently, novel species associations were created which may have dramatically altered species interactions that organised and structured communities.

Changing climate could affect the marine phototrophs of SE Qld, with many species at or near either their southern or northern distribution limits in this tropical to temperate biogeographic overlap zone. Range expansions of tropical species and range contractions of temperate species would potentially alter species composition of marine plant/algal communities and, particularly when foundation species are involved, will impact on marine community structure. Knowledge of the physiology, phenology and the geographical ranges is urgently required to predict the response of marine phototrophs to climate change. Furthermore, extinctions may occur when migrating species are deprived of suitable habitat.

EXOTIC SPECIES

Biological invasions threaten the integrity and function of recipient ecosystems. Human mediated transport of exotic marine species across their natural dispersal barriers has probably occurred for centuries (Adams 1983; Ribera & Boudouresque 1995), with only a small proportion of introduced species becoming invasive. According to the 'tens rule', the probability of an introduced species becoming established in the wild and then for an established species to become invasive is on average 10 % for each transition (Williamson & Fitter 1996a, b). Two invasive seagrass species

are known: *Zostera japonica* Asch. & Graebner and *Halophila stipulacea* (Forssk.) Asch., invaders of the North American Pacific Coast and Mediterranean Sea respectively (Ribera & Boudouresque 1995; Kenworthy *et al.* 2006). In contrast, many macroalgal and phytoplankton species have invaded marine ecosystems worldwide (Hallegraeff 1993; Ribera & Boudouresque 1995).

Detecting the presence of exotic marine algal species in Moreton Bay is not straightforward, requiring knowledge of the presence and biogeographical ranges of native species resident within the ecosystem as well as the regular monitoring of species composition to detect newly-arrived exotic species (Valentine & Jablonski 1993; Jackson 1994). Biotic surveys of shipping ports, marinas and adjacent areas, often entry points for exotic marine species, are best undertaken by teams of taxonomic experts capable of identifying exotic species, including invasive cryptic species misidentified as their native congeners (Gavio & Fredericq 2002; Cohen *et al.* 2005; Thomsen *et al.* 2005; Arenas *et al.* 2006).

The pressing need for detailed species-level taxonomic and ecological information to identify putative introduced species is well illustrated by the *Caulerpa taxifolia* (Vahl) C. Agardh and *Pfiesteria* scenarios. Well known since the 1980s as a Mediterranean invader (Meinesz & Hesse 1991), the green macroalga *C. taxifolia* is indigenous to tropical/subtropical Australia (Phillips & Price 2002), and a common inhabitant of Moreton Bay seagrass communities (Young & Kirkman 1975). This refutes the suggestion of Pillen *et al.* (1998) that exotic *C. taxifolia* was invading Moreton Bay. Reports of introductions of the toxic dinoflagellate *Pseudopfiesteria shumwayae* (Glasgow *et al.* Burkholder) Litaker, Steidinger, Mason, Shields *et al.* Tester (as *Pfiesteria shumwayae* Glasgow *et al.* Burkholder) into Australian estuaries identified only by 'species-specific' PCR probes applied to environmental samples are now considered erroneous (Park *et al.* 2007a, b). Monitoring of Australian estuaries failed to find the species and subsequent studies with rDNA *Pseudopfiesteria shumwayae*-specific primers produced 'false-positive' reactions with the dinoflagellate

Cryptoperidiniopsis brodyi Steidinger *et al.* Litaker, suggesting that the latter species common in Australian estuaries had previously been misidentified as *Pseudopfiesteria shumwayae*.

RARE AND THREATENED SPECIES

Rare species generally have restricted geographical ranges, specific habitat requirements and small population size (Rabinowitz *et al.* 1986). Rarity is considered to be one factor which could determine the extinction risk of a species (Gaston 1996). Threatened species are assigned to various categories: critically endangered, endangered, vulnerable or rare (IUCN 1994). In contrast to terrestrial species, marine species have only been recently recognised as 'at risk of extinction', largely due to insufficient data available on geographical range, habitat specificity and minimum viable population size which determine the conservation status of these species (Phillips 1998b). Many marine species are now known to have restricted geographical ranges (Roberts & Hawkins 1999; Knowlton 2001; Roberts *et al.* 2002) and declining populations, largely decimated by habitat degradation and loss.

With further research, rare and threatened SE Qld species will be identified as requiring protection, similar to many marine macroalgal species afforded protection in other areas of the world. These include vulnerable rapidly declining endemic Mediterranean species of the brown algal genera *Cystoseira* and *Sargassum* (Ballesteros *et al.* 1998; Boudouresque *et al.* 2005; Thiery *et al.* 2005), 15 rare Canadian marine macroalgal species (Hawkes 1991) and 27 threatened macroalgal species from the Wadden Sea (Nielsen *et al.* 1996). Conservation of British macroalgae has progressed from 40 species targeted for priority conservation (John & Brodie 1996) to approximately 260 species on a working list of 'rare' species (Brodie *et al.* 2005). The seagrasses *Enhalus acoroides* (L.f) Royle, *Halophila johnsonii* Eiseman in Eiseman *et al.* McMillan, *Halophila decipiens* Ostenf., *Zostera asiatica* Miki and *Zostera caulescens* Miki are listed as rare or threatened species on other continents (Kenworthy *et al.* 2006).

Knowledge of species abundances and distributions are required to determine extinction risk. In addition, rare species are often difficult

to survey and identify and relatively little tends to be known of their ecology. There are rare endemic macroalgal species in the SE Qld flora such as the brown alga *Tomaculopsis herbertiana* Cribb known only from Caloundra and Byron Bay. Other local macroalgal species are obviously at risk, particularly species of the Dasycladales which are habitat specialists, typically growing in shallow estuaries, which are often the sites of human-mediated disturbance and habitat destruction.

PROTECTING MARINE BIODIVERSITY

Increasing pollution and habitat destruction caused by the rapidly increasing human population of SE Qld threatens to destroy the marine biodiversity of the region unless substantial efforts are directed towards protecting the biota. Marine Protected Areas (MPAs) such as the Moreton Bay Marine Park (MBMP) are zoned as multi-purpose areas to fulfil various social, economic, regional and pragmatic criteria (Ballantine 1991; Salm & Price 1994), ranging from recreation zones to fisheries management areas to preservation zones with strict protection (Gubbay 1995). Only preservation or 'no take' zones carefully defined with respect to location, size and the comprehensive and adequate representation of species, habitats and ecosystems will adequately protect biodiversity (McNeill 1994; Kelleher *et al.* 1995; Agardy 1995, 2000; Jameson *et al.* 2002; Lubchenco *et al.* 2003). However, few MPAs including the MBMP have been designed with sufficient scientific input to achieve appropriate boundaries and sizes (Jameson *et al.* 2002). In the absence of biotic data, the frequently-used easily-measured cost-effective abiotic surrogates are inadequate compared to local-scale rigorous biological surveys and habitat mapping for zoning MPAs (Edgar *et al.* 1997; Stevens & Connolly 2004).

Current zoning of MBMP aims to protect 'iconic' species (dugongs, turtles) and high profile marine habitats as coral reefs, mangroves and seagrass beds (Annon. 1997). These habitat types account for <10% of the MPA area (Stevens & Connolly 2005), protecting areas perceived to have high value rather than protecting a full range of habitats representative of the biodiversity in the MPA. As < 1% of the MBMP is currently zoned as 'no take' zone, which equates to the full protection given to

terrestrial national parks, the current rezoning planning needs to follow international best practise in MPA management (National Research Council 2000; Roberts & Hawkins 2000; Roberts *et al.* 2003) and designate 'no take' zones of 30–50 % of the MBMP area including all habitat types if we are to make serious attempts to conserve the marine biodiversity of SE Qld. This benchmark has already been set by the recent rezoning of Great Barrier Reef Marine Park where the network of 'no-take' areas increased to at least 20% of all 'bioregions' in the park and 33% of the overall MPA area (Fernandes *et al.* 2005). The Final Zoning Plan for MBMP must also outline the adaptive management strategies with clearly defined goals, measurable outcomes, and rigorous biotic sampling and data analyses in order to determine whether the management is effectively protecting biodiversity.

The scientific rigor gained from local scale habitat mapping and habitat classification schemes are prerequisites for delimiting ecological boundaries necessary for defining representative areas for MPA planning (Stevens 2002). An inclusive approach using subtidal transects on an almost bay-wide scale (Stevens & Connolly 2005) provided a quantum leap forward in the knowledge base on the extent and distribution of habitat types in MBMP rather than the rehash of previously published incomplete data largely on iconic groups reproduced in a large number of reports (eg Brisbane River Management Group, 1996, Dennison & Abal 1999). Stevens & Connolly (2005) documented previously unknown habitats, including deep water algal reefs, and discovered previously unrecorded seagrass meadows. While video-recording permits the collection of much cost effective data and has immense value in mapping habitat extent and type, the next logical step is to determine the species composition and abundance of all biota occurring in the habitat types. Monitoring using rigorous sampling and analyses is crucial to determine the present status of species (how many? where? increasing or decreasing?) in order to determine if the management strategies for the MBMP are effectively conserving biodiversity. It should be remembered that not all habitats of the same type have a similar species composition, evident

from the sponge fauna of 10 Sunshine Coast reefs, which recorded 34% species endemism per reef and 60% of the 247 species as rare (Hooper & Kennedy 2002). Important questions to be evaluated if MPAs are to protect biodiversity include whether MPAs preserve the largest possible number of species, including endemic species and whether the surviving habitat fragments are large enough to sustain populations indefinitely.

FUTURE RESEARCH DIRECTIONS

Conservation biology relies heavily on detailed knowledge of the interconnected fields of taxonomy, systematics, ecology, and biogeography (Clarke 1992; Carlton 1993; National Research Council 1995), and endeavours to maintain and protect biodiversity (including little understood and overlooked species) at all spatial scales (Clarke & May 2002; Kenworthy *et al.* 2006). I have outlined a number of knowledge gaps that hamper the development of effective environmental management and conservation strategies for marine algae and cyanobacteria of SE Qld. These are summarised below, along with recommended research directions.

1. Studies on taxonomy and systematics using both traditional (morphology, anatomy, breeding barriers etc) and molecular methods are urgently required to establish well defined taxonomic boundaries for described species, identify cryptic species, and describe species new to science. This new information should be collated into algal/cyanobacterial field guides and floras to facilitate accurate species identification necessary to include these species in ecological studies and in environmental and conservation management strategies.

2. Considerable efforts should be directed towards developing and undertaking a well designed rigorous program of quantitative surveys documenting species composition and abundance. This will allow a better understanding of the structure of marine algal/cyanobacterial communities of SE Qld. Such a sampling program needs to be conducted over long time scales, as the 'short termism' of most ecological surveys (a year or less) can neither document the spatial and temporal changes caused by the complex ecological processes affecting community structure (Lewis 1996;

Bianchi & Morri 2000; Hiscock *et al.* 2003), nor separate natural variability (effects of slow processes, episodic phenomena, high annual variability) from anthropogenic impacts (Southward 1991; Hiscock *et al.* 2003; Thibaut *et al.* 2005).

3. Important areas for algal/cyanobacterial conservation need to be identified and designated in the SE Qld region. Areas of high conservation significance are defined as those containing outstanding assemblages of rare, threatened, vulnerable and/or endemic species, or an exceptionally rich flora, or an outstanding example of a habitat type of known algal/cyanobacterial importance.

4. Greater attention should be paid to determining whether environmental management policies are successful, development is truly sustainable, and areas of high conservation significance are adequately protected. Environmental management and conservation planning decisions must be based on scientific data gained from monitoring programs determining the ongoing status of species and communities (Bourdoursque *et al.* 1995; Bianchi & Morri 2000). For example, the detection of many local population losses may be the early warning signal necessary to avert a species' path to global extinction (Ehrlich & Daily 1993). Extinction is irreversible, once a species has become extinct there are no management or conservation strategies which can restore that species.

5. The human race, including those living in SE Qld, needs to accept the challenge to reduce the current unprecedented global loss of biodiversity, projected to be two-thirds of all species by the end of this century (Raven 2002). We need to preserve and manage natural ecosystems in the face of escalating anthropogenic threats before these systems collapse and can no longer provide us with the resources and services on which we depend. We are the custodians of the planet, and unless we act now to preserve biodiversity, we will be judged harshly by future generations.

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